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**DESCRIPTION AND REVIEW OF GLOBAL MEASUREMENTS OF
ATMOSPHERIC SPECIES FROM GASP**

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Abstract

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A large volume of atmospheric constituent data is being collected in the global airlines by specially equipped B-747 aircraft. This NASA program also obtains data from the similarly equipped NASA CV-990 aircraft during dedicated flights such as a recent near pole-to-pole latitude survey mission. Aerosol composition data are also collected with a NASA F-106 aircraft. Present measurements include ozone, carbon monoxide, water vapor, aerosol and condensation nuclei number densities, sulphates, nitrates, and the chlorofluoromethanes. Meteorological and flight parameters are also recorded for use in data analysis. The present aircraft operations obtain data between 6 and 13.5 km from 65° N between Europe and the north Pacific, and from 23° S over S. America and 42° S over New Zealand. Typical constituent data from the aircraft operations during the first one and a half years are presented. Instrumentation is discussed.

Key Words: Air Quality; Trace Constituent Measurements; Atmospheric Ozone; Water Vapor; Carbon Monoxide; Aerosols; Troposphere-Stratosphere; Meteorology.

Introduction

This report describes the NASA Global Atmospheric Sampling Program (GASP), including the aircraft system, measurement instruments, aircraft distribution data, and atmospheric constituent data. These latter data include ozone, carbon monoxide, condensation nuclei, water vapor, and aerosols.

Since March 1975, the NASA GASP program has been collecting upper atmospheric constituent data with specially instrumented B-747 aircraft flying commercial air routes. The completely automated GASP system [1] uses in-situ measurement techniques to obtain data on selected trace species. The resultant data base is used to describe local and seasonal variations of these trace species. The NASA CV-990 research aircraft is equipped with a similar automatic system to obtain constituent data during dedicated flights into less-travelled areas of the world. This GASP system complements data obtained by research scientists flying remote sensing and prototype instruments on the CV-990 [2]. Another NASA research aircraft, the F-106, is used to supplement GASP B-747 filter data on the chemical composition of atmospheric aerosols. Vertical profiles of aerosol species and off-route data are obtained by this aircraft.

The GASP program was initiated to provide baseline information on atmospheric constituents which could be used with other data sets and with computer models to assess the effects of aircraft exhaust emissions on the upper atmosphere. This assessment effort was prompted by studies conducted several years ago [3,4]. The results of a more recent study [5] predict a lesser effect of aircraft emissions on

atmospheric ozone. This latter study does recommend and suggest, however, continued research in certain problem areas, including studies of the dynamics in the region of principal aircraft traffic. It also recommends the simultaneous measurement of the concentrations of several species critical to ozone destruction and production as a function of altitude and latitude. The data from the NASA GASP program have already provided information and progress in both areas [6,7]. These results indicate that the GASP data will help achieve the NASA goal of understanding the basic physics, chemistry and transport in the upper atmosphere.

In this report, the automated system and its operation are outlined. Sampling routes for the B-747s are presented along with operational data describing the distribution of GASP data with altitude and latitude. Concentration data for ozone, carbon monoxide, and condensation nuclei are presented as typical data obtained by the B-747 automated system. Measurements of total ozone and in-situ water vapor obtained from the recently completed CV-990 Latitude Survey Mission [2] are also presented. Data on atmospheric sulphate concentrations in the vicinity of the tropopause, obtained from the F-106 aircraft, are shown.

The GASP program operates systems on four B-747 aircraft. One system is flown by United Airlines, two are flown by Pan American World Airways, and one is flown by Qantas Airways of Australia. One of the Pan Am aircraft is the B-747 SP (Special Performance) version, which provides higher altitude and longer range capability.

Description of Measurement System

As part of the Global Atmospheric Sampling Program, NASA Lewis has installed automated atmospheric measurement systems on four B-747

aircraft and the NASA CV-990 research aircraft. System installations were completed between December 1974 and August 1976. The aircraft and their in-service dates are shown in Fig. 1. The systems are standardized to allow for ease in servicing and the interchange of GASP instruments among the airplanes. The following paragraphs will review, first, the airflow system which provides the sample air to the measurement instruments; second, how the system on the B-747 is controlled and how the data is acquired; and, third, the instruments which obtain the data.

Airflow System

Air samples for the in-situ measurements enter the GASP system through two tubes fixed in a capped inlet probe mounted on the bottom of the fuselage. A schematic of the GASP system installation is shown in Fig. 2. The probe is open whenever the aircraft is above 6.1 km. One of the inlet tubes ducts atmospheric air through air sample lines to the instruments in the GASP equipment rack which is installed below the first class passenger cabin. This air is pressurized by the pump package and regulated to one atmosphere before it flows through the ozone and carbon monoxide instruments. Other air bypasses the pump to flow directly to the condensation nuclei counter, the whole gas sample collection system, and the nitric oxide analyzer.

Another portion of the atmospheric air entering the air sample inlet probe flows around the right side of the aircraft to the previously described filter collector mechanism. After flowing through the paper filter, the air passes through a venturi for a measurement of the flowrate. Filter collector systems are mounted on the regular B-747's flown by United Airlines and Pan Am.

The second tube in the inlet probe ducts air to the particle sensor unit. Particles in the visible range are counted according to size. This unit is mounted as close to the inlet probe as possible, in order to minimize particle loss in the particle inlet line. This second tube is designed to sample isokinetically at cruise conditions.

After being sampled, the air which flowed through the instruments on the GASP equipment rack, and through the filter collector, is dumped from the aircraft through overboard vents on either side of the aircraft.

Data Acquisition/Control

The automatic operation of the GASP system is controlled by a dedicated computer, which operates whenever power is applied to the aircraft. The computer, called a Data Management Control Unit (DMCU), is programmed to obtain a data point or calibration point as often as every five minutes while the aircraft is above 6.1 km. The computer and a Flight Data Acquisition Unit (FDAU) together access the constituent, meteorological, and aircraft operations data obtained by the GASP instruments. They also access data through a tie-in with the aircraft's Inertial Navigation System (INS). These data are recorded by a digital cassette recorder on magnetic tape cassettes.

The computer is programmed to recognize special events and to record these events in the data. As an example, continuous real time recordings of data are obtained during periods of high vertical acceleration (greater than 1.2 G or less than 0.8 G) and during collection of whole air samples. The exposure periods for GASP filter samples are also controlled by this system as are zero point and span checks conducted on selected instruments in flight.

The measurement instruments are turned on during aircraft preflight. The computer takes over control just prior to take-off. A standby condition is held until a signal is received by the processor from the altimeter to set up the system for sampling. A basic 60-minute sampling cycle is constructed by alternating 5-minute sample and calibration modes. Thus, there are six sample readings and six different calibrations taken each cycle. All data are recorded during a 16-second period at the end of each 5-minute mode. Not all instruments require the full six calibrations each hour. Where calibration data are not needed, air sample readings are taken. Before landing, the system is returned to a standby condition.

Constituent Measurement Instruments

The GASP systems are equipped to measure the concentrations of a number of atmospheric constituents. These include both gaseous and particulate species. Except for the whole air samples and the aerosol filter collections, all of the constituents in Table 1 are being measured at least as often as every ten minutes during system operation. The measurement of nitric oxide is scheduled to begin in August 1977 with an instrument in the GASP automated system on the NASA CV-990 research aircraft. Installation of other nitric oxide instruments on the B-747s will occur in the later months of 1977.

Most of the constituent measurement instruments have been described elsewhere [1], so only a short statement of each instrument's principle of operation is provided. Each instrument's measurement range is shown in Table 1.

Ozone

In-situ measurements are obtained with an ultraviolet absorption photometer. The difference in measured intensity of an ultraviolet beam (at 2578 Å) passing through the atmospheric sample and an ozone-free air sample is an indication of the ozone mixing ratio. As an aid in calibration, a zero measurement, of ozone-free air, is made once each hour during flight. The ozone is removed by passing the air through activated charcoal. Periodic tests are made on each aircraft to determine the percentage of ozone destruction which occurs in the inlet lines and the pressurization system. The appropriate corrections are then made to the ozone data.

Carbon Monoxide

Local values of the carbon monoxide mixing ratio are obtained with a nondispersive infrared analyzer. The instrument uses a dual isotope fluorescence principle. Zero gas measurements are obtained every twenty minutes during flight by flowing the air sample through a heated catalytic scrubber. Tests to measure the gain of the electronic circuit are also made automatically in flight.

Condensation Nuclei

Ambient concentrations of condensation nuclei (CN) are obtained with a cloud chamber type of instrument. Reliable measurements can be made at concentrations as low as 30 nuclei/cm^3 . In the instrument, water is condensed on any particle larger than about $0.003 \mu\text{m}$ in diameter. This condensation is produced by adding water to the air sample and suddenly reducing the pressure inside the instrument's cloud chamber. The particles which result can grow to $20 \mu\text{m}$ in diameter. The actual determination of the number of nuclei in the resulting cloud is made by measuring

the attenuation of a light beam passing through the cloud.

The CN unit is calibrated at NASA-Lewis with a Pollack counter, which has been established as a reference.

In-flight tests on this instrument include a zero test (all particles are removed from the air sample by an absolute filter) and a test of the gain of the electronic circuit.

Data are sampled from the CN instrument at a rate of once a second during the 16-second data recording period. In addition, data every twenty seconds during the four minutes prior to the data recording period (hence 12 additional CN values) are stored and then recorded during the period. Once an hour, for five minutes, an instrument range change extends the instrument upper limit to $30\,000\text{ nuclei/cm}^3$, in order to measure the possible occurrence of clouds or aircraft wakes.

Water Vapor

The GASP system presently obtains measurements of water vapor with an aluminum oxide hygrometer. In the future, measurements will be made with an instrument which employs the chilled mirror technique. Flight tests of this latter instrument on the CV-990 have shown it to be more reliable. This chilled mirror instrument will soon be installed on the B-747 aircraft.

With this instrument, a cooled mirror is exposed to the sample flow such that a thin layer of dew or frost is formed. An optical system senses mirror reflectance and operates a thermoelectric cooler to maintain the mirror temperature at the dewfrost point.

Nitric Oxide

The nitric oxide concentrations will be measured with a chemiluminescent instrument. Zero measurements will be made in-flight. Span measurements will also be made with a 1 ppbv concentration of nitric oxide calibration gas carried with the instrument. This instrument may also provide a measurement of nitrogen dioxide in the future when the nitrogen dioxide to nitric oxide converter currently under development is perfected.

Aerosols

The chemical compositions of typical atmospheric aerosols are determined from measurements of airborne material collected on filter paper by the GASP filter collector system. Present filter materials exposed during flight efficiently collect material which is identified by ion chromatographic analysis in the laboratory. The present analysis is for anions, including sulphates, nitrates, chlorides, and fluorides. Analysis for cations may be added during the next year.

Aerosol particle size and number density is obtained by an instrument using a light scattering principle. Flight test experience with this instrument indicated that flight through a cloud resulted in a particle size distribution that is significantly different from that of a clear air sample, mainly in the total count of the largest size particles. A simple cloud detector is therefore obtained by observing the counting rate of the largest size particle.

Whole Air Samples

The GASP system uses a grab sampling method to acquire whole air samples which are analyzed by gas chromatography. Specially treated stainless steel flasks are purged and filled at flight altitudes and then

analyzed at Lewis for the chlorofluoromethanes, F-11 and F-12. Other methods are being explored in order to obtain measurements of nitrous oxide, carbon tetrachloride, and other compounds in the whole air samples.

Meteorological and Support Data

In addition to the above atmospheric constituent data, the GASP system also records Supplemental Data, as listed in Table 2. These data augment the constituent data and are used to correlate it in statistical studies. The data of Table 2 are all recorded with the Greenwich Mean Time. As a direct result of these measurements, data on the local sun zenith angle and the local value of the tropopause can be calculated. The tropopause data which correspond to local aircraft position, are derived from space and time interpolations into the National Meteorological Center gridded tropopause pressure arrays.

Route Structure

The airlines currently flying the B-747 aircraft equipped with the automated GASP systems were chosen initially for the global coverage they provided. The routes currently flown by their B-747s are shown in Fig. 3. High density of aircraft traffic in these corridors. It also is desirable because the majority of the earth's anthropogenic activity is in this region. Polar route coverage is desirable to characterize the entire hemisphere, while southern hemisphere coverage is desirable to characterize global and interhemispheric differences and transport.

The United, Pan Am, and Qantas B-747s equipped with GASP systems obtain data in the northern mid-latitudes at various locations around the globe. In addition the Pan Am 747 SP obtains data on sub-polar flights as high as 65° North latitude. The Pan Am and Qantas aircraft obtain data, for interhemispheric comparisons, in the southern hemisphere

to 42° south over Australia, New Zealand, the Indian sub-continent, and occasionally on flights into South Africa and into Brazil. Other coverage is obtained by the CV-990 aircraft, which recently flew over the Pacific Ocean between 75° N and 61.5° S during its recent Latitude Survey Mission, during dedicated missions.

Distribution of GASP Data

NASA-Lewis has been obtaining data from the GASP program since the first system began returning data on the United Airlines 747 in March 1975. The GASP data obtained between March 1975 and September 1976 has been analyzed for its distribution over altitude, latitude, and longitude. This data, averaged over 5° increments, is shown in Fig. 4. It shows that about 80 percent of GASP data was taken between 20° and 60° North latitudes. The southern hemisphere data fraction will quadruple after the Qantas aircraft, which began returning data in July 1976, is in operation for twelve months. Otherwise this distribution of GASP data by latitude should be representative of future data, unless the airlines make major changes in their B-747 air routes.

These GASP data were also distributed by flight altitude. This distribution is shown in Fig. 5. In this initial nineteen month period, about seventy percent of GASP data were obtained between 10.1 and 11.9 km. The data at 12.5, 13.1, and 13.7 km are predominately from flights of the Pan Am 747 SP which flies, on the average, 1.2 km above the regular B-747s. The small peak at 6.4 km is a result of the GASP system operation. A data point is always taken immediately after system set-up at 6.1 km. When these data are analyzed with respect to the local tropopause height, constituent distributions can be obtained over a pressure interval of up to ± 200 hPa from the tropopause.

Analysis of GASP data shows a longitudinal distribution which tends to peak near high density airports located in the major air corridors, including the continental United States, Hawaii, Australia, Tokyo, and Western Europe.

Constituent Data

The GASP program is obtaining simultaneous measurements of the species in Tables 1 and 2, except for nitric oxide. This report presents data on the measurements of ozone, carbon monoxide, and condensation nuclei on the B-747 aircraft, as well as data from the CV-990 and F-106 aircraft.

Flight Records

The data base for ozone has been accumulating since March 1975. The carbon monoxide and condensation nuclei data are limited and their data bases are still small. While they accumulate, however, some observation can be drawn from examination of individual flight records. One such flight record is shown in Fig. 6. Data for ozone, carbon monoxide, and condensation nuclei were obtained during a flight from Los Angeles to Honolulu. The data are shown versus longitude, along with the static air temperature and aircraft flight altitude.

The concentration of these species are indicative of a tropospheric air mass. Ozone mixing ratios are almost entirely below 150 ppbv and do not exhibit much variability. The carbon monoxide mixing ratios are typically tropospheric, northern mid-latitude values [8]. The uniformity of the data and its low variability indicates upper tropospheric air. The data for condensation nuclei are within the expected range of values for tropospheric air. This particle data, with its peaks near 122 W and 152 W longitude, may actually be typical of clouds, or typical of jet aircraft influence as suggested by others. The study of many such

flight records would be needed, however, to prove either case. Examination of similar flight records, which are obtained in the stratosphere, show increased levels of ozone along with reduced levels of carbon monoxide and condensation nuclei. These data are also typical of data obtained by other investigators.

Sets of simultaneously acquired atmospheric data, like the ozone, carbon monoxide, and condensation nuclei data of Fig. 6, can be used to study several possible effects. The extent of an inverse correlation between ozone and condensation nuclei and or carbon monoxide can be evaluated. Also, the distribution of these species and their gradients through the atmosphere can be found and documented.

Vertical Ozone and Temperature Profiles

The local ozone data obtained by the GASP program during 1975 were analyzed with respect to the height above or below the tropopause, the difference is in hPa. The distribution presented in Fig. 7 shows an ozone mixing ratio in the troposphere of approximately 50 ppbv. Above the tropopause, the mixing ratio increases rapidly with increasing distance above the tropopause. This almost classical description of ozone agrees well with the 1976 Standard Atmosphere Ozone profile which assumes a tropopause height at 11 km. If aircraft affect the local ozone mixing ratio by 5 to 10 percentage points, as suggested in one study [5], GASP data of this type over several years will show it.

The vertical profile of the static air temperature obtained from the GASP data is also shown in Fig. 7. It also shows the classical distribution. Its average minimum value is at -58°C in close agreement with -56°C from the Standard Atmosphere.

Ozone data from the GASP program for 1975 and early 1976 have been

analyzed in this and other formats. Consistency has been shown [7] with historical data from the 1960 decade North American ozonesonde network. The GASP ozone data base is now large enough to obtain distributions of ozone with respect to altitude, latitude, and in bimonthly ozone distributions. Researchers under NASA contract have used the GASP data in their ozone transport studies and in making estimates of the flux of stratospheric ozone into the troposphere at the mid-latitudes [6]. Other researchers are using GASP ozone and particle data in studies of the troposphere.

Water Vapor

NASA utilizes the CV-990 research aircraft to obtain atmospheric constituent data in regions not travelled by commercial airlines. The recent NASA-Latitude Survey Mission [2] over the Pacific Ocean was one such flight series involving the CV-990 aircraft and its GASP system. Concurrent with the automated system, researchers operated prototype instruments in the CV-990 to evaluate them for possible adaptation to other systems including satellites. This procedure has been used to evaluate instruments for the B-747 system.

During the survey mission, data on the latitudinal distribution of water vapor, among other species, was obtained with the GASP chilled mirror hygrometer as shown in Fig. 8. The data have been averaged over 5° latitude increments for two different altitudes. The structure in the two curves reflects to a certain extent the interaction between the atmosphere's primary circulation cells. The peaks near the equatorial region show the upwelling of the tropical air. A similar distribution, not shown, at 10 km was obtained by the B-747 aluminum oxide hygrometer for the same period. Data from the B-747 aircraft will make possible the

determination of seasonal distributions.

Total Ozone

Another prototype instrument evaluated on the CV-990 during the Latitude Survey Mission was an ultraviolet spectrophotometer (UVS). This instrument obtained UV flux data in several radiation bands which were then analyzed for an indication of the total ozone overburden above the aircraft [9]. Corrections for the ozone underburden were made using the aircraft altitude, and the local ozone mixing ratio. Data from the UVS were compared with data from overflown Dobson stations in the southern hemisphere. The agreement was within ± 2 percent. The ratios of UVS to Dobson total ozone values are shown in Fig. 9. The UVS values were almost always less than the Dobson values. Another result of the UVS system on the CV-990 Latitude Survey Mission was the derivation of a latitude profile of total ozone, as shown in Fig. 10. The data shows the expected result, a minimum in the equatorial region and maximum values near the poles. Data south of 30° south latitude include variations caused by differences in time and longitude.

Analysis of the frequency of GASP measurements in daylight and the repetitiveness of GASP flight routes throughout the year indicate that UVS total ozone systems on GASP aircraft could provide a valuable complement to Dobson station and satellite total ozone measurements. It would also be very useful in a program to cross calibrate ground based total ozone stations.

Sulphates

NASA-Lewis used an F-106 aircraft to develop the filter collection system and to provide filter samples used in the efforts to develop the filter analysis techniques. Special flight series deployed from

several sites between 30° and 45° N latitudes over the last several seasons have collected a number of filter samples which reveal the distribution of sulphates and nitrates below and above the local tropopause. The data in Fig. 11 show sulphate data in the upper troposphere and lower stratosphere. The data in the lower stratosphere exhibit greater variability than the data in the upper troposphere. The higher mean value in the lower stratosphere indicates a possible sulphate source in the lower stratosphere. A larger number of filter samples will be needed to characterize the origin and seasonal variations of this possible source.

Concluding Remarks

The NASA Global Atmospheric Sampling Program has been obtaining atmospheric constituent and related meteorological data for two years. Four B-747 aircraft equipped with an automated measurement system and the NASA CV-990 and F-106 aircraft have all been obtaining data of interest to researchers in the fields of atmospheric science meteorology. The report discusses the measurement system, and some of the typical results obtained from the collection and analysis of the first one and a half years of atmospheric data by these aircraft.

1. Distributions by latitude and altitude show that most GASP data are obtained in the Northern mid-latitudes between 20° and 60° . Due to the varying height of the local tropopause, both by latitude and by season, the GASP data are distributed primarily between 200 hPa above and below the tropopause.

2. Mean levels of ozone from GASP measurements agree well with historical data and profiles contained in the U.S. Standard Atmosphere. GASP data show inverse relationships between ozone and carbon

monoxide, and ozone and condensation nuclei concentrations.

3. Measurements of water vapor from the CV-990 aircraft show latitudinal distributions which indicate the locations of the intersections of the primary atmospheric circulation cells found in the northern and southern hemispheres.

4. Total ozone measurements derived from ultraviolet spectrophotometer (UVS) data agree within ± 2 percentage points with independent measurements from Dobson ozone ground stations. A latitude profile of total ozone from the UVS is presented.

5. Sulphate concentrations measured by the filter collector system on an F-106 aircraft show greater variability and higher values in the lower stratosphere as compared to data from the upper troposphere. These data indicate a possible local source for sulphates at or above the tropopause.

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TABLE I. - GASP MEASURING INSTRUMENTS

<u>Species</u>	<u>Principle/range</u>
Ozone	Ultraviolet absorption photometer range 3 ppb to 20 ppm
Water vapor	Cooled mirror hygrometer dew-frost point range -80° to $+20^{\circ}$ C
Carbon monoxide	Infrared absorption analyzer range 0.02 to 1 ppm
Nitric oxide	Chemiluminescent analyzer range 0.05 to 10 ppb
Aerosols	Light scattering sensor/(D > 0.3 μ m) ion chromatography/(anions)
Condensation nuclei	Cloud chamber minimum ₃ concentration 30/cm ³
Whole air samples	Electron capture gas chromatography/F-11, F-12

TABLE II. - SUPPLEMENTAL DATA

Flight data
 Time & date
 Latitude
 Longitude
 Altitude
 Air speed
 Heading

Meteorological data
 Outside air temp.
 Wind direction
 Wind velocity
 Turbulence (vertical accel.)
 Cloud encounters



Figure 1. - Airline 747 aircraft participating in NASA global atmospheric sampling program.

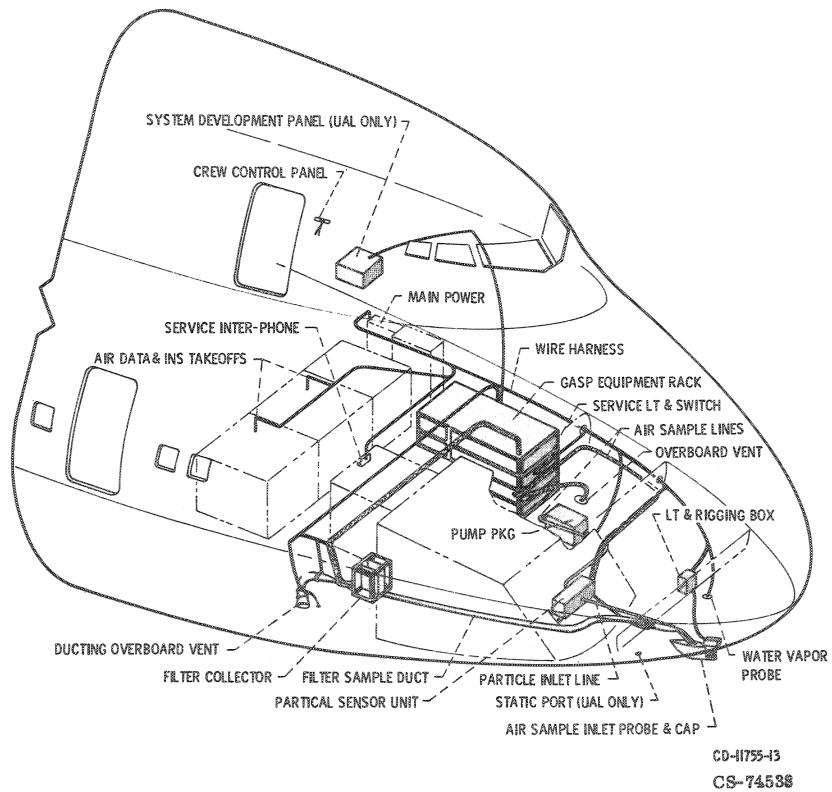


Figure 2. - Global air sampling program system installation on B-747.

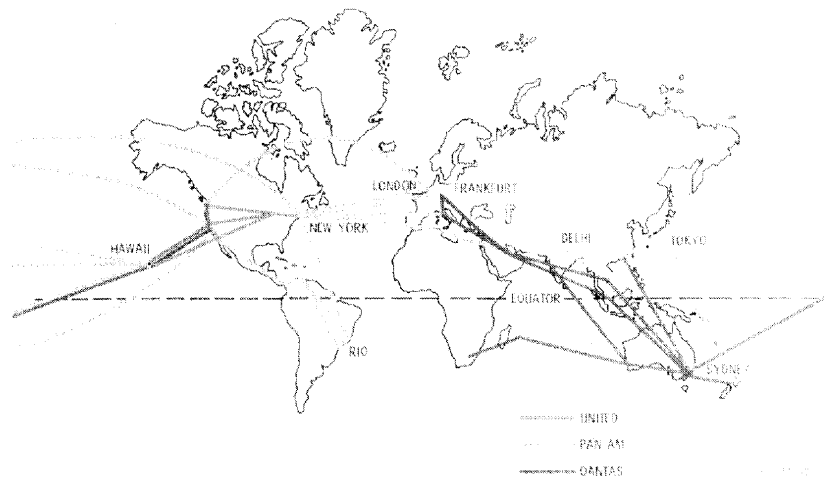


Figure 3. - GASP route structure.

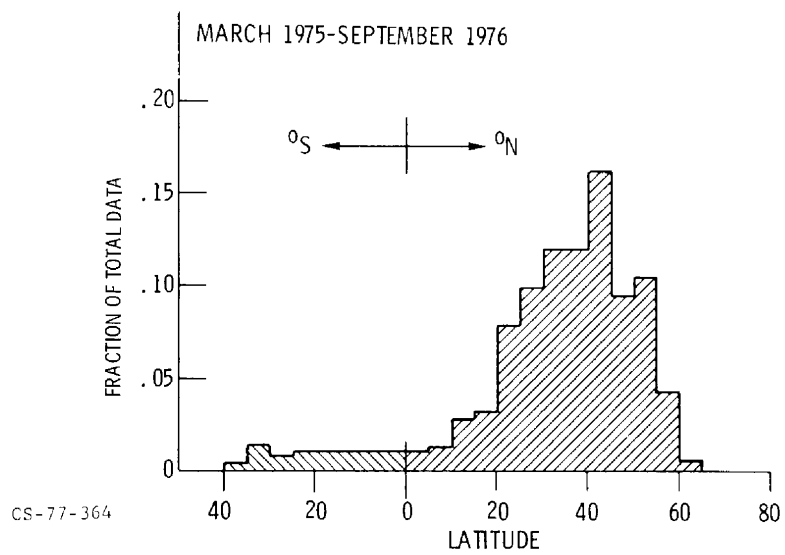


Figure 4. - Distribution of GASP data by latitude

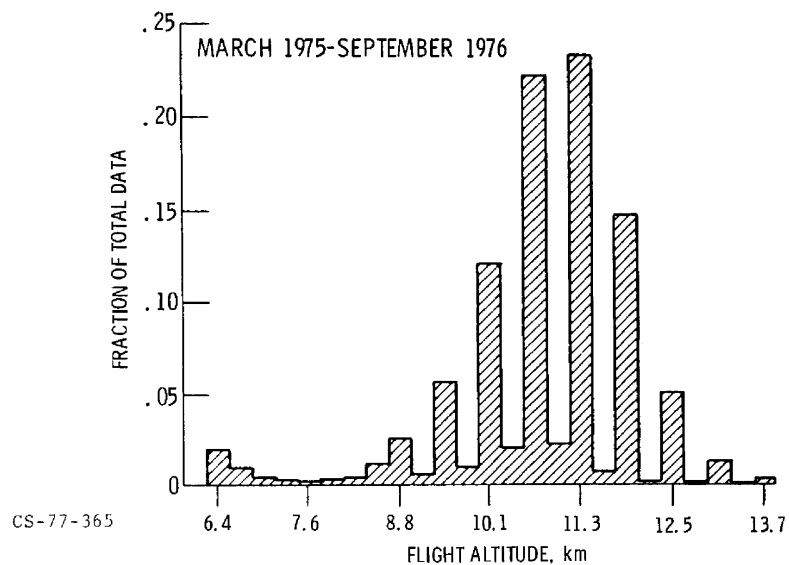


Figure 5. - Distribution of GASP data by flight altitude.

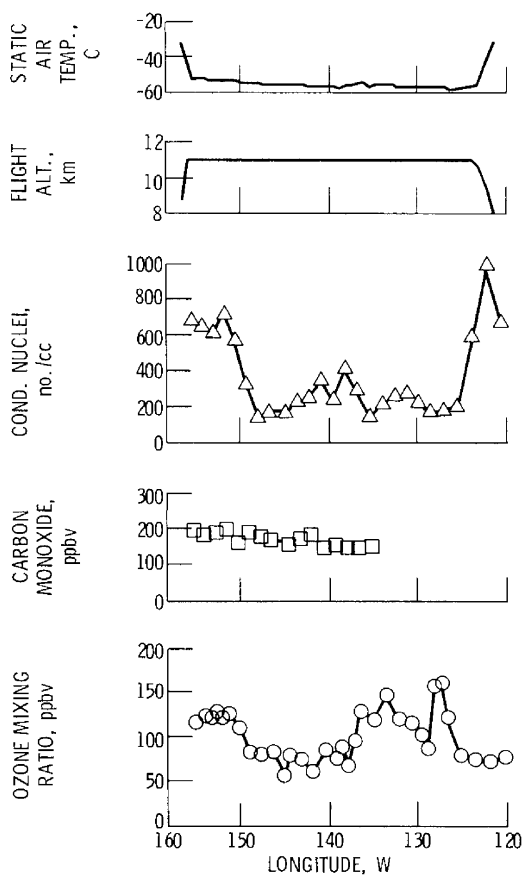


Figure 6. - Ozone, carbon monoxide, and condensation nuclei data obtained with the automated GASP system during a flight from Los Angeles to Honolulu.

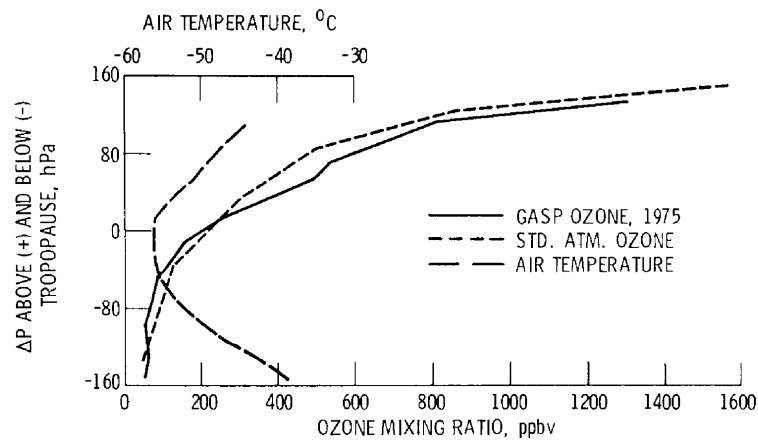


Figure 7. - Vertical ozone and temperature profiles with respect to NMC tropopause.

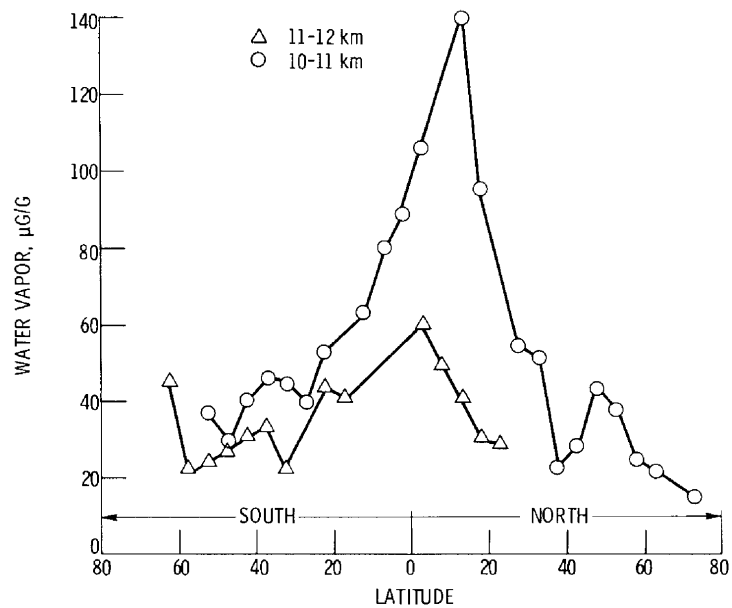


Figure 8. - Latitudinal profile of the water vapor mixing ratio, data were obtained during the CV-990 latitude survey mission of 1976.

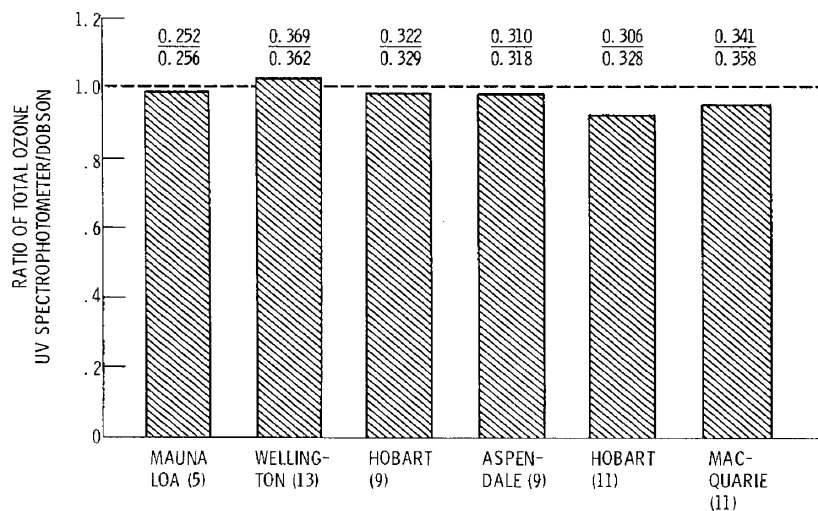


Figure 9. - Comparison of total ozone observations by a UV spectrophotometer and various Dobson ground stations, for flights in parenthesis.

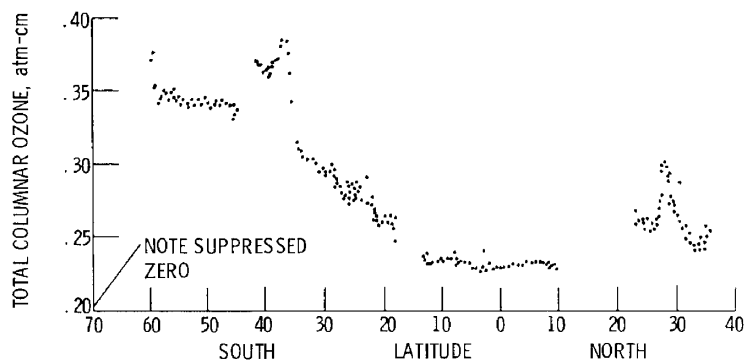


Figure 10. - Latitude profile of total ozone derived from UVS measurements for November 1976 (taken from ref. 9).

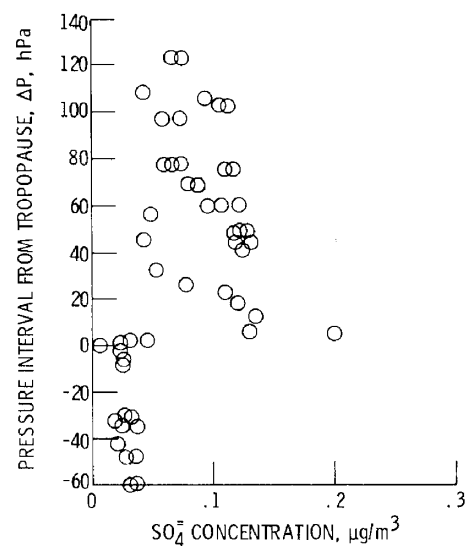


Figure 11. - Variation in sulphate concentration between stratosphere and troposphere.